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ABSTRACT

Fifteen subjects performed in a visual target detection task that took place in a simulated broad-band, sonar monitoring display. Over a one-hour test session, subjects attempted to detect two types of targets presented at an average rate of 3/minute on a continuously updated waterfall display. Event-related brain potentials were recorded in response to the two classes of targets (growing lines of lighted pixels that simulated an acoustic source in the surroundings and briefly flashed vertical lines) as well as to two types of irrelevant "probe" stimuli (occasional tone pips and diffuse flashes of the video screen). ERP amplitudes were significantly related to target detection performance in several ways. A late positive component (P300) was enlarged in response to correctly detected targets, particularly in subjects who were performing with a high level of accuracy. Specific ERP components elicited by both targets and irrelevant probes during the first 6 minutes of the session were found to be predictive of subsequent performance accuracy during the hour-long session in subjects studied under both alert and drowsy conditions. These findings suggest the application of ERP measures to evaluate fitness for duty of operators in task situations requiring a high level of vigilance, such as radar and sonar operators, air traffic controllers, etc.

A number of physiological measures of brain activity have been evaluated as indicators of attention, alertness and task performance in vigilance situations where subjects are required to detect and respond to sensory signals over a prolonged period. The discovery of such indicators has clear applicability for enhancing the performance of individuals whose jobs require maintaining a high level of vigilance for lengthy intervals, such as air traffic controllers, radar and sonar operators, pilots, long-distance vehicle drivers, etc. Reliable physiological indices of the sensory, perceptual, and cognitive functions that underly task performance could be used to monitor and predict operator effectiveness and to provide feedback signals for maintaining an optimal state of alertness and preparedness to react to key signals.

Among the electrophysiological indices of sustained performance that have been studied are various frequency bands of the ongoing EEG as well as several components of the event-related brain potentials (ERPs). Lapses of vigilance and periods of diminished performance have been consistently reported to be associated with amplitude increases in the theta band of the EEG (Beatty et al., 1974; O'Hanlon and Beatty 1977; Gale et al., 1977; Townsend and Johnson 1979; Belgavin and Wright 1987; Torsvall and Akerstedt 1988; Makeig and Inlow, in press). Reliable changes in the alpha and beta bands have also been reported in some of these studies, but their covariation with performance was more task-dependent.

Among the ERPs that have been studied in vigilance tasks are the N1-P2 components of the auditory evoked potential, which decline in amplitude over sustained periods of stimulation (Ohman and Lader 1972; Picton et al., 1976) and the later "N2" wave (latency 250-350 msec) that is specifically enlarged during periods of drowsiness and sleep (Weitzman and Kremen 1965; Picton et al., 1976). In a recent study, Makeig, Elliot, Inlow and Kobus recorded auditory ERPs to task-irrelevant probe tones that were presented continuously throughout a 28-minute vigilance session in which subjects attempted to detect threshold level noise bursts as a simulation of a passive sonar detection task. It was found that the probe-evoked ERP amplitudes could be used to predict short-term lapses in vigilance; probes presented immediately before correctly detected targets ("hits") elicited larger N1 and smaller N2 components than did probes that preceded "missed" targets. It was suggested that ERPs to non-intrusive probe stimuli may serve as an effective means of monitoring operator alertness during sustained task performance.

The present study is aimed at evaluating the utility of the irrelevant-probe ERP approach to predict operator performance in a visual target detection task that simulates the passive broadband display currently used in operational sonar systems. This

display presents information in the form of a moving "waterfall" on which an array of 50 horizontal lines of pixels varying in intensity is continually updated. New information is presented every half-second as a new horizontal line is added to the top of the display, which is "pushed down" as successive rows appear. The horizontal axis of the display represents the bearing of the acoustic "target" source, the vertical axis represents time in half-second increments, and the brightness of the pixels represents the intensity of the target sound source.

Subjects were required to detect two types of targets in this display. A growing vertical line of lighted pixels (growing target) simulated an actual acoustic source in the surroundings, and a brief flash of a vertical line (flashed target) was used to assess further the perceptual sensitivity of the observer. Each type of target occurred on a random time schedule at an average rate of 3 per minute. In addition to the two types of targets, subjects were also presented with two kinds of irrelevant "probe" stimuli. Auditory probes consisted of 1000 Hz, 60 dB tone bursts presented through headphones at a rate of 10 per minute, and visual probes were flashes of the entire pixel display, given at a rate of 5 per minute.

ERPs were recorded to the task-relevant targets and to both the auditory and visual probes. In addition, ERPs time-locked to the ongoing screen-updates were recorded as another form of visual probe. Since we were mainly interested in observing ERP signs of performance deterioration, most subjects were studied in late night or early morning sessions when they reported themselves to be drowsy. Possible relationships between these ERPs and indices of target detection accuracy were evaluated in several different ways. First, comparisons were made between those subjects who maintained alertness and performed well over the one-hour vigilance session and those who performed poorly. Second, ERPs were examined over the first six minutes of the hour-long sessions in order to find out if overall level of performance could be predicted at the outset; these predictive relationships were tested both between and within subjects. Third, within-subjects comparisons of ERPs were made for seven subjects who were tested under under both drowsy and alert conditions. Fourth, ERP correlates of momentary lapses of vigilance were examined by selectively averaging the ERPs to probes that preceded hits and missed targets, respectively. Finally, a correlational analysis was undertaken to determine the fluctuations in performance over the course of the session in low-performing subjects (quantified in 3-minute blocks) were paralleled by changes in any of the ERP measures.

METHODS

Subjects

Subjects were 15 right-handed males between the ages of 18 and 30, recruited from among students at the University of California, San Diego. All subjects reported normal hearing, and normal or corrected-to-normal vision. Subjects were paid for their participation.

Stimuli

Subjects were instructed to attend to a simulation of a "passive broad-band" (PBB) sonar display, presented on a video monitor. This simulation consisted of a 50 row by 128 column array of dots, each dot in turn constituting a 2 X 2 array of screen pixels. The entire simulation screen subtended visual angles of 4.4 degrees vertical and 7.8 degrees horizontal at a distance of 1 meter.

In a PBB display, each row of dots represents one 360-degree sweep of the ship's microphones, with the brightness of the dot at a given bearing representing the loudness of the broad-spectrum noise coming from that direction. In the simulated display, each dot was pseudorandomly assigned one of 4 grey levels from bright white to black, to mimic random environmental noise (e.g., from ocean waves).

The display was presented as a "moving waterfall": Every 0.5 seconds, a new row of dots appeared at the top of the array, with all other rows moving down one place, and the bottom row disappearing. This addition of a new row is called a "screen update." The vertical axis thus encompassed the last 25 seconds of screen updates, with the most recent information at the top of the screen.

Two types of visual target stimuli were embedded in the background noise on a randomized schedule. One type, called "growing targets", consisted of a continuous vertical row of bright white dots appearing at any location (bearing) across the top of the simulation screen and growing longer by one dot with each screen update. (In an actual PBB display, a steady source of noise from a given direction -- e.g. another ship's engines -- appears as a continuous streak of bright pixels growing down from the top of the screen). These lines grew for six seconds (i.e., to a length of 12 dots), at which time the entire line of dots changed color from bright white to bright red and then disappeared (being replaced by random "noise" dots). The other type of target, called "flashed targets", consisted of a continuous vertical line of five bright white dots flashed simultaneously

for 50 msec at a pseudorandomly-selected bearing at the top of the simulation screen. Both of these types of target stimuli were presented at an average rate of 3 per minute, with the interval between successive targets of the same type varying pseudorandomly between 16 and 24 seconds.

Two types of irrelevant probe stimuli were also presented. The visual probes consisted of all dots on the simulation screen changing to bright white for 50 msec, then reverting to their previous grey levels. This happened at an average rate of 5 times per minute, with the interval between successive visual probes varying pseudorandomly between 8 and 16 seconds. Auditory probes consisted of a 1000 Hz sine-wave tone lasting 50 msec, with 10 msec onset and offset ramps, presented at 60 dB SL over headphones. Auditory probes appeared at an average rate of 10 per minute, with the interval between successive auditory probes varying pseudorandomly between 4 and 8 seconds.

The timing of target and probe stimuli was constrained so that at least one second elapsed between stimuli of any type, with one exception: The most frequent type of stimulus, the auditory probes, were occasionally presented within the first three screen updates (1.5 seconds) of a growing target. Since short vertical lines often appeared in the "background noise" of the simulation -- due to chance juxtaposition of bright white dots in successive rows -- these probes occurred before subjects could confidently identify the simultaneously-presented targets.

Procedure

After the simulation task was demonstrated and explained and electrodes were attached, subjects were seated in an easy chair in front of a video monitor in a sound-proofed, electrically-shielded room. They were instructed to attend to the display and to report the detection of growing targets by pressing a button held in one hand and the detection of flashing targets by pressing a button held in the other hand. Hand of response was counterbalanced across subjects. Subjects were warned to withhold pressing the appropriate button until a growing target was long enough to be discriminated confidently from background noise, but to press before it turned red. Accuracy rather than speed was emphasized for detections of both targets. Subjects were not required to fixate their eyes but instead were allowed to scan across the top of the simulation screen. Before the recording began, subjects performed a practice run lasting 2 minutes. The recording session consisted of 60 minutes of continuous monitoring, with no breaks.

ERP Recording

Brain electrical activity was recorded from scalp sites Fz, Cz, Pz, C3, C4, P3, P4, T3, T4, T5, T6, O1, and O2 of the International 10/20 System via a commercially available electrode cap. Vertical EOG (from electrodes placed directly above and below the right eye) and horizontal EOG (from electrodes at the right and left external canthi) were recorded via Ag/AgCl electrodes attached to the skin with adhesive collars. All sites were recorded referenced to the left mastoid, and later digitally re-referenced to the average of the two mastoids. All electrode impedances were reduced to below 5 K-ohm before recording. The potentials were amplified with an 8-second time constant and a low-pass half-amplitude cutoff of 60 Hz (midline sites, VEOG, and HEOG), or with high- and low-pass half-amplitude cutoffs of 0.1 and 100 Hz respectively (lateral sites and A2). The amplified signals were digitized at a sampling rate of 256 Hz and stored on magnetic tape for later averaging.

RESULTS

Between Subject Comparisons

On the basis of their accuracy at detecting the visual targets, the first 10 subjects studied were divided into three groups, termed low (N=4), medium (N=3), and high (N=3) performers (see Table 1). The ranges of percent correct target detections (averaged over both the "growing" and "flashed" targets) in these groups were: low (18-49%), medium (61-67%) and high (78-84%). Virtually no false alarm responses were made by any of the subjects.

ERPs to Targets. The ERPs elicited by the growing targets at the moment they turned red (having achieved a length of 10 pixels) included a prominent late positive component (P300) with a broad midline scalp distribution, preceded by an N200 component over occipito-temporal areas. As seen in the high performing subjects (Figure 1), the P300 had a much shorter latency, a more sharply peaked waveform at 300-350 msec and a more anterior scalp distribution for hits than for missed targets.

The amplitude of the P300 to both hits and missed growing targets was considerably reduced in the medium and low performing groups ($p<.01$) (Figure 2, Table 2). P300 amplitude to correctly detected flashed targets was also diminished in the lower performing groups (Figure 3, Table 2), but this difference only approached significance due to large inter-subject variability within groups. As reported in previous studies (reviewed in Hillyard and Picton 1987), missed targets were associated with very small P300's that did not differ significantly from zero.

P300 amplitudes were also determined for the target ERPs during the first six minutes of the session, to see whether the above inter-group differences were evident from the outset. Substantial between-group amplitude differences were observed for the growing targets (Table 3), but not for the flashed targets; P300 amplitudes to the growing targets were reduced in the low performing subjects, particularly for missed targets. This marked ERP difference was evident even though the detection rates of growing targets were approximately equivalent for the three groups during the first six minutes (Table 3, numbers in parentheses).

ERPs to Irrelevant Auditory Probes. The irrelevant tone probes elicited the classic auditory "vertex potential" comprised of an N1 component at 90-110 msec and a P2 component at 180-200 msec. Over the entire session the low performer group showed reduced N1-P2 amplitudes (Figure 4) although this difference only

approached significance (Table 4). Over the first 6 minutes of the session, however, the N1-P2 peak-to-peak amplitude was significantly smaller in the low performers then in the others (Figure 5, Table 4).

ERPs to Irrelevant Visual Probes. The ERPs to the irrelevant flashed probes included a positive, occipital dominant component at 120 msec latency, followed by a negativity peaking at 150-180 msec and a broad positivity over 200-500 msec. The latter two waves were largest over the central and parietal scalp. The screen updates elicited an ERP with a small negative deflection peaking at 120-150 msec over posterior scalp areas. Due to high inter-subject variability none of these visual ERP components showed reliable relationships to task performance.

Within Subjects Analysis

Three of the initial ten subjects as well as five new subjects were tested in two separate runs under conditions of drowsiness and alertness, respectively. The times of day for these runs were selected by each subject as representing his most alert and most drowsy period. All but one of the subjects showed diminished performance during the time of day selected for drowsiness (Table 5). This subject's (#23) data were not included in the following analyses.

The question of major interest in these within-subjects analyses was whether ERP measures obtained during the first 6 minutes of the session were predictive of overall target detection performance throughout the session. In particular, ERPs recorded during the first six minutes of the alert session were compared with those recorded during the first six minutes of the drowsy session for all of the task stimuli.

Behavioral parameters during the first six minutes were not consistently correlated with target performance over the entire 60-minute session. As shown in Table 6, four of the seven subjects actually had higher target detection rates during the first six minutes of their drowsy run than their alert run. Similarly, Table 7 indicates that subject's reaction times (RTs) to the targets during the first six minutes were not consistently different between the alert and drowsy runs; indeed, in several subjects these RTs were somewhat faster during the drowsy run. This failure of initial behavioral performance measures to predict subsequent target detection accuracy during the session provided the rationale for examining the predictive value of the ERP measures recorded during the first six minutes.

ERPs to Targets. The P300 elicited by growing target (hits) was significantly reduced during the first six minutes of the drowsy session with respect to the alert session (Figure 6, Table 8). This difference was present in 6 of the 7 subjects. There were too few artifact-free "miss" trials for growing targets in most subjects to be able to obtain reliable ERP averages. The P300 to the flashed targets did not differ significantly between the drowsy and alert runs.

ERPs to Irrelevant Visual Probes. The ERP to the irrelevant flashed probes included a major positive deflection between 200-500 msec that was largest at the Cz site (Figure 7). This late positivity was significantly larger during the first six minutes of the alert run than the drowsy run (Figure 7, Table 8). This difference was present in 6 of the 7 subjects.

The ERP elicited by the regular screen updates consisted primarily of a negative wave that onset at 90-100 msec and peaked at 120-150 msec over posterior scalp sites. Since the screen updates occurred every 500 msec, the 800 msec tracings shown in Figure 8 include two such responses. This negative "N1" response was significantly larger during the first six minutes of the alert than the drowsy run (Figure 8, Table 8). This difference was evident in six of the seven subjects at the left occipital electrode site (O1) (Figure 9).

ERPs to Irrelevant Auditory Probes. The auditory probes elicited somewhat larger N1 and P2 components during the first six minutes of the alert run than the drowsy run (Figure 10), but these differences did not reach significance over the group of seven subjects (Table 8). However, if those three subjects who showed the largest decrement in overall performance during the drowsy run (subjects 15, 18, 19) were considered separately, it was apparent that the auditory probes evoked larger P2 waves during the first six minutes of the alert run than the drowsy run (Figure 11); this difference was marginally significant statistically ($p<.06$). The reliability of these waveform changes, however, is evident when the ERPs were divided arbitrarily into two subsets according to whether the probes happened to occur prior to growing targets or flashed targets. Since the growing and flashed targets were presented in random order, these two ERP subsets amounted to two random samples from the overall ERP. As shown in Figure 12, these two ERP subaverages were highly reproducible in waveform within the first six minutes of the drowsy run and the alert run, but were clearly differentiated between those two runs. This shows that each individual subject's auditory probe ERP displayed characteristic waveform changes at the beginning of the drowsy run that were associated with subsequent decremented performance.

Trial by Trial Relation of ERPs to Performance.

In order to find out whether differences in the auditory probe ERPs would be predictive of correct performance on a trial-by-trial basis, ERPs were averaged selectively for probes that occurred within an eight-second interval preceding hits versus missed targets, respectively. This comparison is shown in Figure 13 for the drowsy runs of the three subjects (15, 18 and 19) who showed the largest performance decrements. For these subjects the probes that preceded missed targets elicited enlarged N2 waves peaking between 250-325 msec, although the waveform of this change was different for each individual. Subjects 15 and 18 also showed a consistent decrease in the N1 amplitude to probes in the pre-miss interval, together with an increase in P2 for subject 18. The reliability of these subject-specific waveform differences for probes preceding hits versus misses is illustrated in Figure 13; the ERPs to probes preceding growing targets and flashed targets showed equivalent effects. These results indicate that probe evoked ERP components can track fluctuations in performance accuracy throughout the one hour session in drowsy subjects.

In order to examine the time course of these relationships over the one-hour session, probe ERPs were averaged over successive three-minute intervals, and ERP measures were compared with the accuracy of target detections during these periods. This analysis was carried out for the drowsy session of those same subjects (15, 18, 19) who showed consistent predictive relationships between probe-evoked ERP components N1 and/or N2 and detection accuracy.

For subject 15 (Figure 14) there was a progressive decline in the detection of growing targets over the first 18 minutes of the session. The period of poorest performance (18-27 minutes) was marked by enlarged N2 amplitudes to the probes, resulting in a highly significant overall correlation between percent-correct detections and N2 peak amplitude ($\underline{r}$ = 0.59, df=18, p<.01). The detection of flashed targets was also low during the 18-27 minute period, but fluctuations in percent hits at other times were not paralleled by N2 changes, so this overall correlation was not significant. The correlation of flashed target percent hits with the N1 amplitude did reach significance ($\underline{r}$ = -0.53, p<.02).

For subject 18 (Figure 15), target detection accuracy was above 50% for the first three minutes, rapidly fell to near-zero levels over the interval 3-21 minutes, then showed fluctuating periods of recovery for the remainder of the session. These variations in target detection accuracy were closely tracked by probe-evoked N2 amplitude variations (quantified as P2-N2 peak/peak measure) for both growing targets ($\underline{r}$ =-0.62, p<.01) and flashed targets ($\underline{r}$ =-0.62, p<.01) Target detectability was also correlated with the probe-evoked N1 amplitude for flashed

targets (r = -0.49, $p<.05$), and the correlation approached significance for growing targets (r =-0.37).

For subject 19 (Figure 16), target detection accuracy was high during the first 10 minutes, slowly declined to reach a low level over the period 20-40 minutes, then recovered during the interval 40-50 minutes. These performance fluctuations were closely tracked by N1 amplitude variations, resulting in significant correlations for both growing (r = -0.52, $p<.02$) and flashed (r = -0.57, $p<.01$) targets. N2 amplitudes were largest during the period of worst performance, but the correlation with detection accuracy only approached significance for growing targets (r = 0.35) and flashed targets (r = 0.38).

DISCUSSION

Several different ERP components were found to be reliably associated with visual target detection accuracy in this simulated sonar task. P300 components were elicited by the task-relevant target events, and their amplitudes and latencies depended upon whether or not the targets were correctly detected and upon the overall level of accuracy during the one-hour test session. For the "growing targets" in the waterfall display, which simulated an acoustic source in the environment, P300 waves were triggered by a color change (from white to red) in the growing line of pixels that was introduced when the line had grown to 12 units over a six-second period. This color change basically served as a feedback signal that informed the subject as to whether his decision about the presence or absence of a target had been correct. This stimulus triggered a large P300 whether it signalled either correct (hits) or incorrect (misses) performance, with the incorrect feedback triggering a P300 of longer latency. These findings are in accordance with previous reports that feedback signals elicit large P300 waves to the extent that they are informative to the subject (Squires et al., 1973; Johnson and Donchin 1978; Ruchkin and Sutton 1978).

The amplitude of the P300 to the color change of the growing targets was strongly associated with overall target detection performance. It was considerably smaller in the group of poorest performing subjects (particularly for missed targets), even during the first six minutes of the session when accuracy at detecting these targets did not differ significantly among groups. Thus, the initial P300 amplitude to growing targets was more predictive of subsequent performance level during the rest of the session than was initial behavioral performance.

The P300 to the growing targets was also predictive of subsequent target detection performance in the seven subjects studied on separate occasions under "drowsy" and "alert" conditions, respectively. In these within-subjects comparisons, the P300 amplitude to correctly detected targets during the first six minutes was significantly larger under the alert than the drowsy conditions. Thus, enlarged P300 amplitudes early in the vigilance session were again associated with heightened alertness and more accurate target detection performance throughout the entire one hour session.

The flashed targets elicited a large P300 when correctly detected and very little P300 activity when missed. The P300 amplitude for hits was more than twice as large in the high performing group (who averaged 85% correct detections) as in the low performing group (34% correct). These results are in accord with previous reports showing that near-threshold signals elicit P300

waves in proportion to the confidence with which they are detected (Squires et al., 1973, 1975). Unlike the P300 to the growing targets, however, the P300 amplitude to flashed target hits within the first six minutes of the run was not predictive of subsequent performance.

The ERPs to the irrelevant visual probe stimuli presented every 8-16 seconds during the first six minutes of the session were also predictive of subsequent target detection accuracy in the within-subjects (but not the between-subjects) comparisons. The ERP to the flashed probes included a late positive component (possibly a P300 wave) that was largest at the vertex electrode over the latency range 200-500 msec. This positivity was larger during the first six minutes of the alert session than the drowsy session. A similar relationship was seen for the negative component at 100-150 msec evoked by the repetitive "updates" of the simulated sonar display every 500 msec; again significantly larger amplitudes were produced during the first six minutes of the alert runs in relation to the drowsy runs.

The ERPs to the irrelevant auditory probe stimuli significantly predicted performance for both between-and within-subject comparisons. The probe-evoked N1-P2 amplitudes were significantly smaller in the low performing subjects; this effect was evident during the first six minutes of the session. The auditory N1-P2 also differed consistently between the alert and drowsy sessions of the three subjects who showed the greatest performance decrement during drowsiness; for probe-evoked ERPs during the first six minutes, this difference was most pronounced in an enlarged P2 component for the alert session. Each individual subject, however, had a characteristic N1-P2 morphology that changed in a reproducible fashion as a function of drowsiness. This suggests that evaluation of probe-evoked N1-P2 morphology changes by means of pattern recognition algorithms would be effective in predicting subsequent performance in tasks of this type.

The irrelevant auditory probes also elicited an enlarged N2 component (at a latency of 250-325 msec) in the low performing subjects during the drowsy session. This "sleep N2" component is characteristically associated with onset of the early stages of sleep (Weitzman and Kremen 1965). In the low-performing subjects, the N2 evoked by probes preceding missed targets was much larger than that evoked by probes preceding hits. Thus, moment to moment fluctuations in alertness resulting in hit or missed targets was accurately reflected in N2 amplitude in the low performing subjects.

The tracking of performance by the probe-evoked ERP was also evident when ERPs and performance were averaged in successive 3-minute blocks across the session. Fluctuations in target detection accuracy were generally correlated with variations in N2

amplitude, with periods of lowest performance showing the largest N2's. The probe-evoked N1 generally showed the reverse pattern--with smaller N1's accompanying poorer performance, although these correlations tended to be less reliable.

Summary and Conclusions

A number of specific ERP components elicited by target stimuli and by irrelevant visual and auditory probe stimuli were shown to have sensitive relationships with subject alertness and with accuracy of target detection performance. ERP measures were identified that (1) differentiated between sessions of high and low performance, (2) tracked moment-to-moment fluctuations in alertness and target detection accuracy, and (3) bore a predictive relationship to performance accuracy later in the session. These findings suggest that ERP measures may be of value in assessing the immediate fitness for duty of operators whose duties require a high level of vigilance such as radar and sonar operators, air traffic controllers, pilots, etc. By recording ERPs from operators at the beginning of their watch periods, predictive measures of subsequent performance decrements may be obtained even though performance itself has not yet begun to deteriorate. ERP recordings may also have application for the non-intrusive, on-line monitoring of operator alertness and effectiveness in order to maintain optimal performance levels throughout the watch period.

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Subject	Time of Day	% Hits – Growing Targets	% Hits – Flashing Targets	Assigned Group
10	*09:00*	*59*	*63*	*medium*
11	*05:30*	*70*	*67*	*medium*
12	00:45	75	83	high
13	23:45	72	84	high
14	23:30	79	90	high
15	*22:30*	*30*	*31*	*low*
16	22:40	22	26	low
17	*22:45*	*51*	*71*	*medium*
18	*06:15*	*18*	*18*	*low*
19	*05:30*	*48*	*50*	*low*

Table 1 – Performance (% correct detection of both types of targets) of the subjects in the experiment. Italics indicate subjects who participated in two sessions.

	low performers	medium performers	high performers	p value
growing targets				
hits (n)	3.36 (162)	7.49 (333)	8.01 (390)	*.01*
misses (n)	1.52 (399)	9.47 (200)	11.86 (127)	*.001*
flashing targets				
hits (n)	4.73 (180)	10.05 (339)	12.37 (454)	.12
misses (n)	0.17 (352)	0.14 (188)	-0.04 (81)	.97

Table 2 – Mean amplitude (in microvolts) of the P300 wave at Pz between 300-600 msec. following targets, for the entire 60-minute experimental run. The numbers in parentheses indicate the number of sums incorporated in the averages.

	low performers	medium performers	high performers	p value
growing targets				
hits (n)	7.22 (34)	9.67 (32)	11.49 (34)	.11
misses (n)	2.05 (25)	12.42 (20)	13.94 (18)	*.003*
flashing targets				
hits (n)	7.23 (32)	8.55 (44)	11.25 (45)	.74
misses (n)	-0.15 (25)	1.26 (5)	3.41 (8)	.37

Table 3 – Mean amplitude (in microvolts) of the P300 wave at Pz between 300-600 msec. following targets, in the first six minutes of the 60-minute experimental run. The numbers in parentheses indicate the number of sums incorporated in the averages.

	low performers	medium performers	high performers	p value
overall				
N1-P2 pp-amp.	11.21	21.59	18.21	.12
P2 mean amp.	3.81	10.38	8.83	.27
1st 6 minutes				
N1-P2 pp-amp.	13.71	27.69	22.60	.04
P2 mean amp.	2.83	12.10	9.98	.09

Table 4 -- Amplitude (in microvolts) at Cz following auditory probes, by two measures: peak N1-P2 (most positive peak minus most negative peak, 80-200ms) and mean P2 (mean amplitude 180-250ms).

Subject	time of day alert	time of day drowsy	% hits, growing targets alert	% hits, growing targets drowsy	% hits, flashing targets alert	% hits, flashing targets drowsy	% hits, all targets alert	% hits, all targets drowsy
5	23:00	*12:05*	61	*29*	52	*34*	57	*32*
10	09:00	*17:00*	59	*41*	63	*49*	61	*45*
11	10:00	*05:30*	69	*70*	85	*67*	77	*69*
15	10:40	*22:30*	51	*30*	67	*31*	59	*31*
17	15:00	*22:45*	47	*51*	89	*71*	68	*66*
18	09:30	*06:15*	77	*18*	91	*18*	84	*18*
19	09:30	*05:30*	89	*48*	92	*50*	91	*49*
23	23:00	*01:35*	59	*57*	73	*75*	66	*66*
MEAN (SD)			65 (14)	*43 (17)*	77 (15)	*49 (21)*	70 (12)	*47 (19)*
MEAN (SD) (1st 7 subjects)			65 (15)	*41 (17)*	77 (16)	*46 (19)*	71 (13)	*44 (19)*

Table 5 -- Performance over all 60 minutes (% correct detection of both types of targets) of the repeated subjects in both sessions.

Subject	time of day alert	time of day drowsy	% hits, growing targets alert	% hits, growing targets drowsy	% hits, flashing targets alert	% hits, flashing targets drowsy	% hits, all targets alert	% hits, all targets drowsy
5	23:00	*12:05*	86	*40*	69	*53*	78	*47*
10	09:00	*17:00*	53	*53*	59	*88*	56	*71*
11	10:00	*05:30*	67	*73*	94	*94*	81	*84*
15	10:40	*22:30*	53	*53*	88	*29*	71	*41*
17	15:00	*22:45*	13	*60*	94	*88*	54	*74*
18	09:30	*06:15*	87	*20*	100	*27*	94	*24*
19	09:30	*05:30*	73	*87*	100	*100*	87	*94*
MEAN (SD)			62(25)	*55(21)*	86(16)	*68(31)*	74(15)	*62(25)*

Table 6 -- Performance in the first six minutes (% correct detection of both types of targets) of the repeated subjects of both sessions.

Subject	time of day alert	time of day *drowsy*	reaction time (msec), growing targets alert	reaction time (msec), growing targets *drowsy*	reaction time (msec), flashing targets alert	reaction time (msec), flashing targets *drowsy*
5	23:00	*12:05*	4318	*4248*	750	*671*
10	09:00	*17:00*	4837	*4606*	543	*580*
11	10:00	*05:30*	4033	*4274*	590	*389*
15	10:40	*22:30*	4909	*4655*	647	*505*
17	15:00	*22:45*	4597	*4495*	783	*759*
18	09:30	*06:15*	4648	*3237*	527	*552*
19	09:30	*05:30*	4622	*4630*	491	*473*
MEAN (SD)			4566 (302)	*4306 (500)*	619 (113)	*561 (124)*

Table 7 -- Reaction times to both types of targets by the repeated subjects in the first six minutes of both sessions.

ERP COMPONENT	MEASURE	MEAN AMPLITUDE alert	*drowsy*	F	p
P300 to growing target hits	mean amp. at Cz, 300-600 msec	11.40	*4.55*	5.74	.05
Late positivity to visual probes	mean amp. at Cz, 200-500 msec	4.11	*2.50*	6.47	.04
N1 to screen updates	mean amp. at O1 & O2, 100-150 msec	-1.11	*-0.61*	6.15	.05
N1-P2 to auditory probes	peak-to-peak amp. at Cz, 80-200 msec	24.72	*22.14*	2.50	n.s.
P2 to auditory probes	mean amp. at Cz, 180-250 msec	10.73	*8.81*	1.57	n.s.

Table 8 -- Measures of ERP components produced by the repeated subjects in the first six minutes of both sessions.

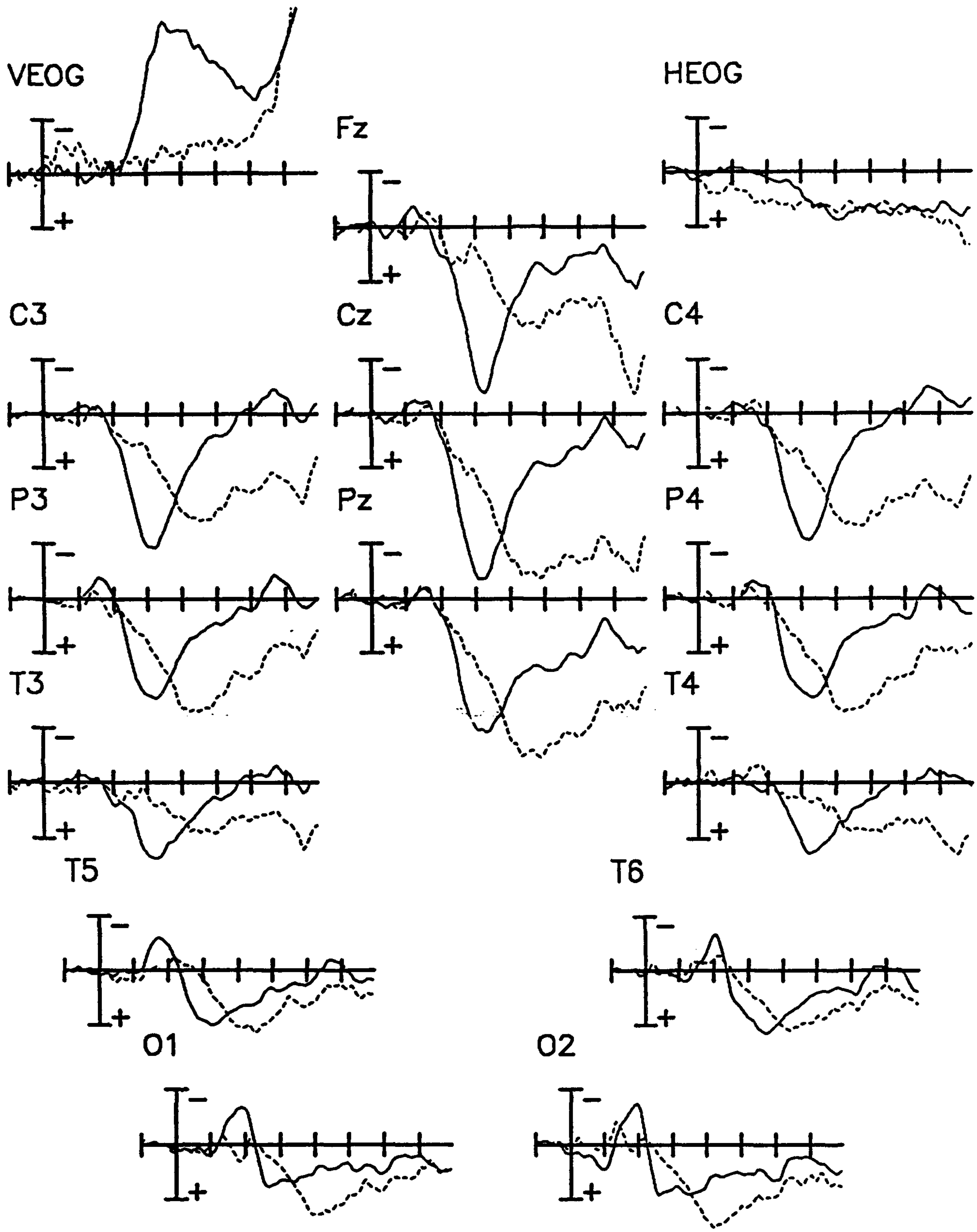

Figure 1 —— ERPs time-locked to the growing target turning red, for subjects with high detection performance. Solid lines are hits, dashed lines are misses. In this and all subsequent figures, the calibration bars are five microvolts (negative plotted up) and the tick marks represent 100 msecs.

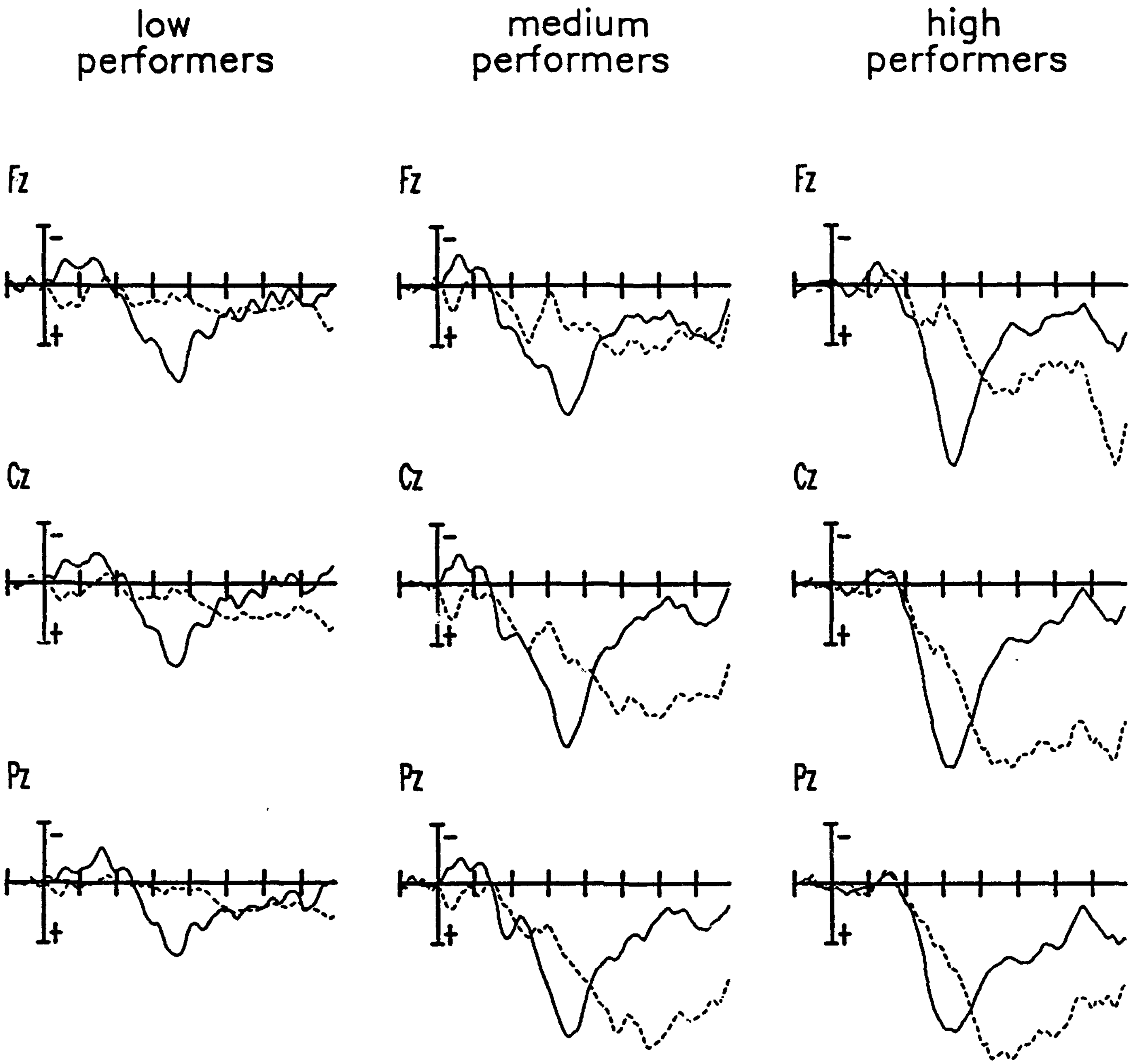

Figure 2 -- ERPs time-locked to red flash of growing targets, at midline sites for three groups of subjects. Solid lines are hits, dashed lines are misses. (Data for the high performance group are the same as in Fig. 1.)

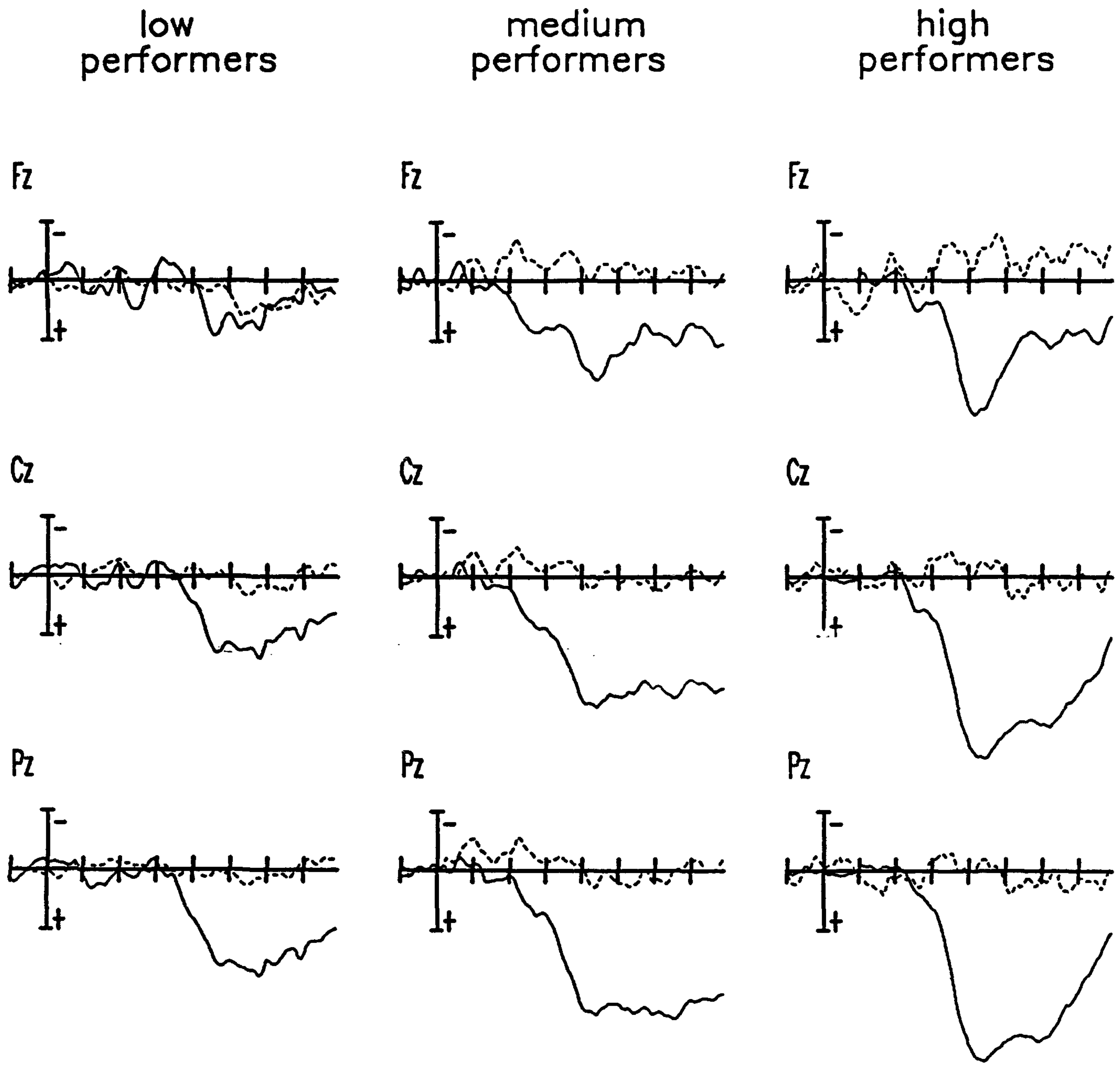

Figure 3 —— ERPs time–locked to the flashing targets, at midline sites for three groups of subjects. Solid lines are hits, dashed lines are misses.

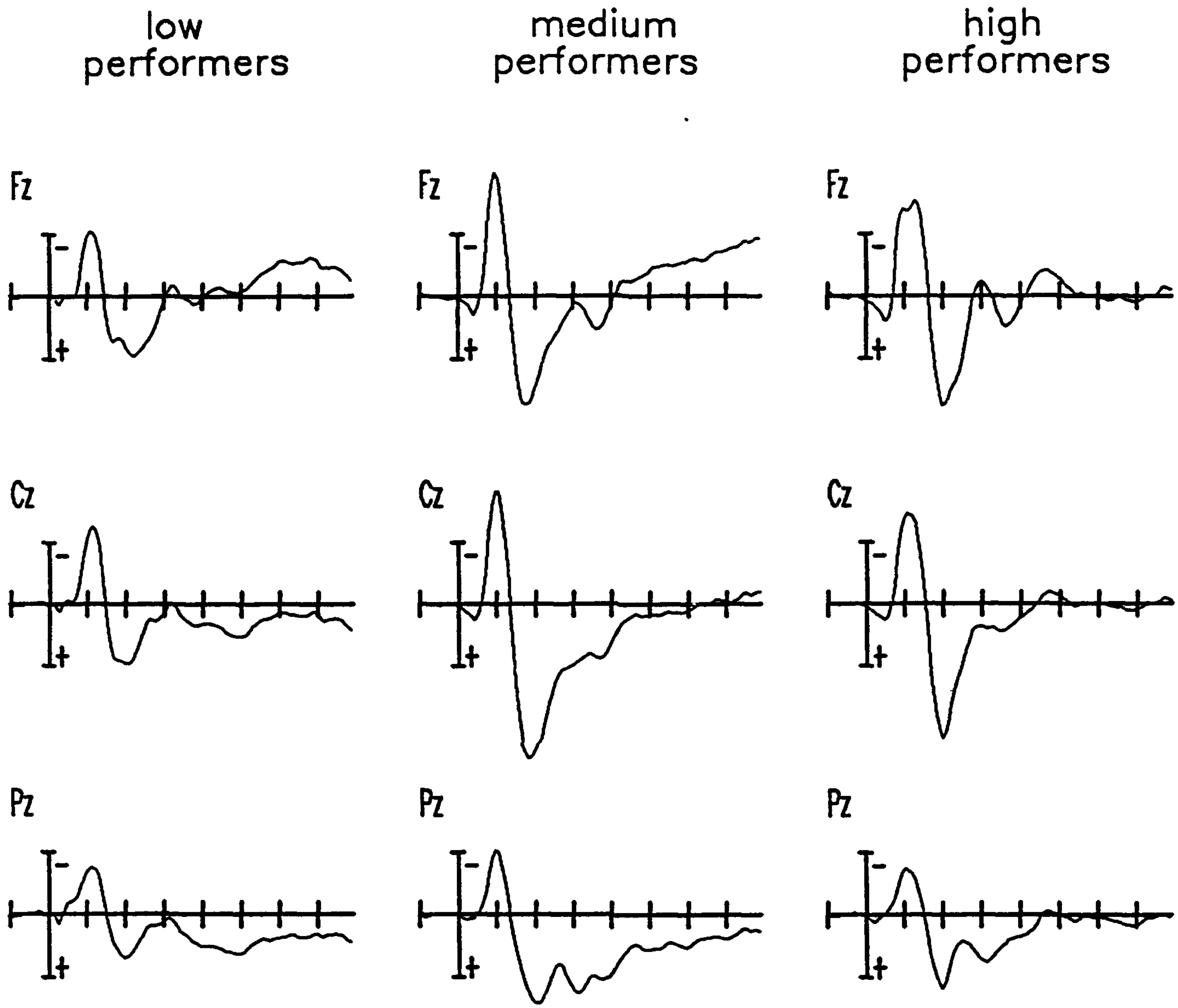

Figure 4 -- ERPs time-locked to the auditory probes, at midline sites for three groups of subjects.

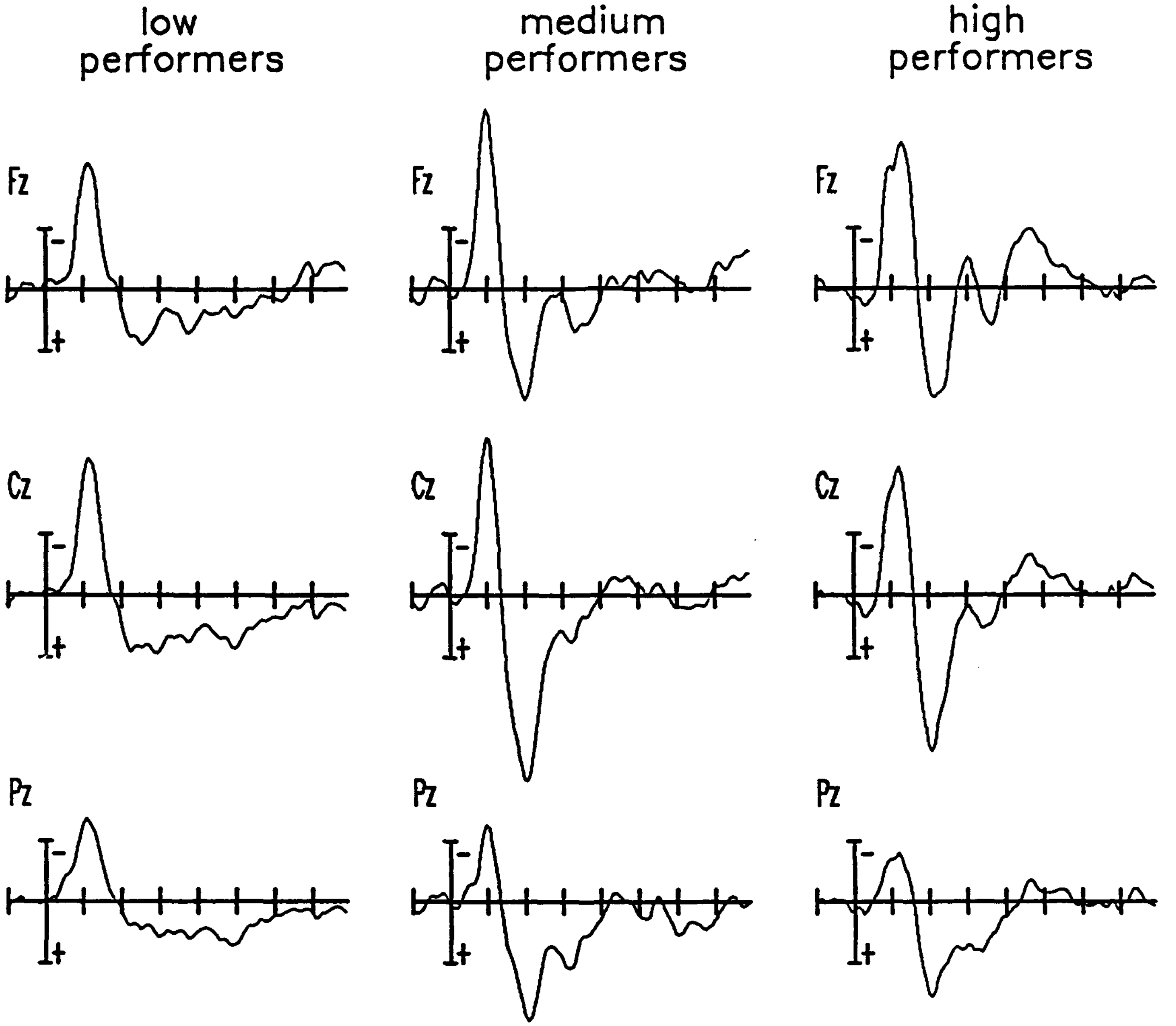

Figure 5 —— ERPs time-locked to the auditory probes during the first six minutes of each 60-minute run, at midline sites for three groups of subjects.

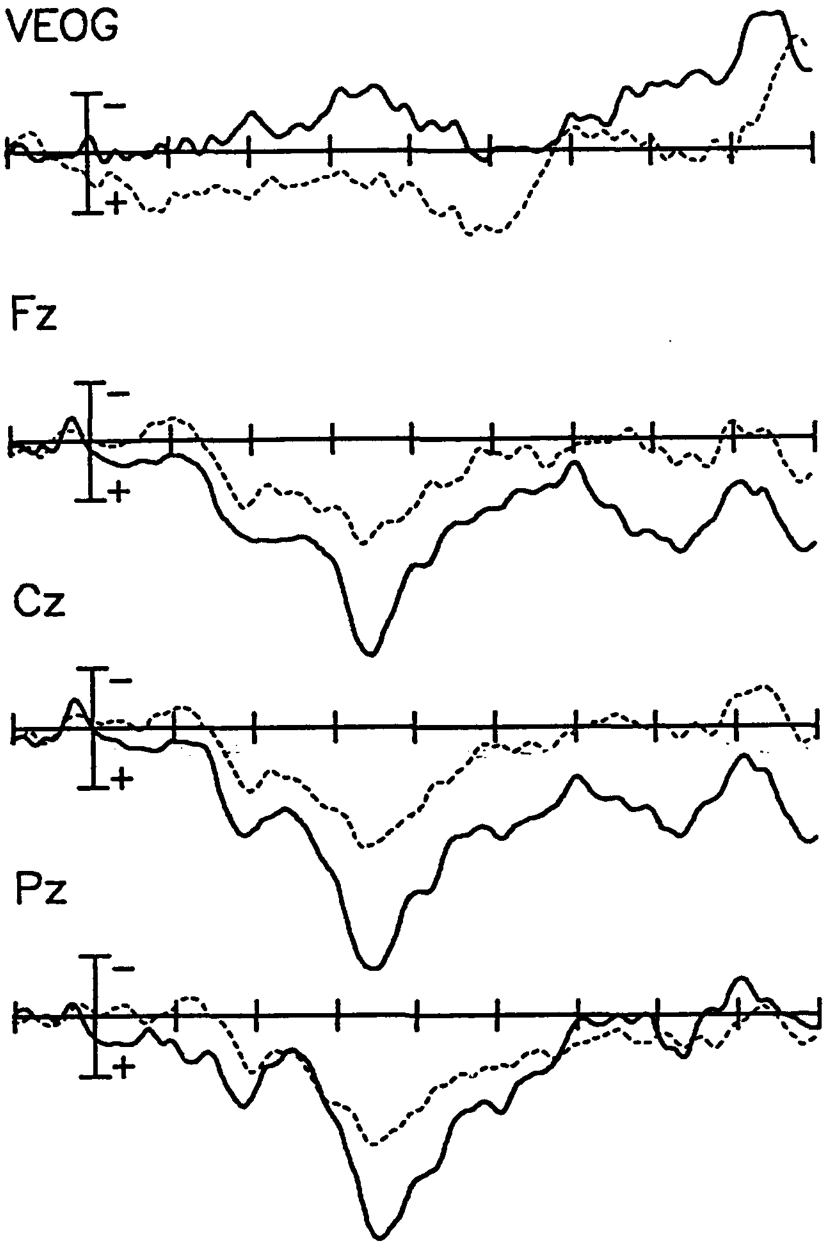

Figure 6 —— ERPs time—locked to the red flash of the correctly—detected growing targets (hits); grand averages of seven repeated subjects. Solid lines are ERPs from the first six minutes of alert runs; dashed lines are ERPs from the first six minutes of drowsy runs.

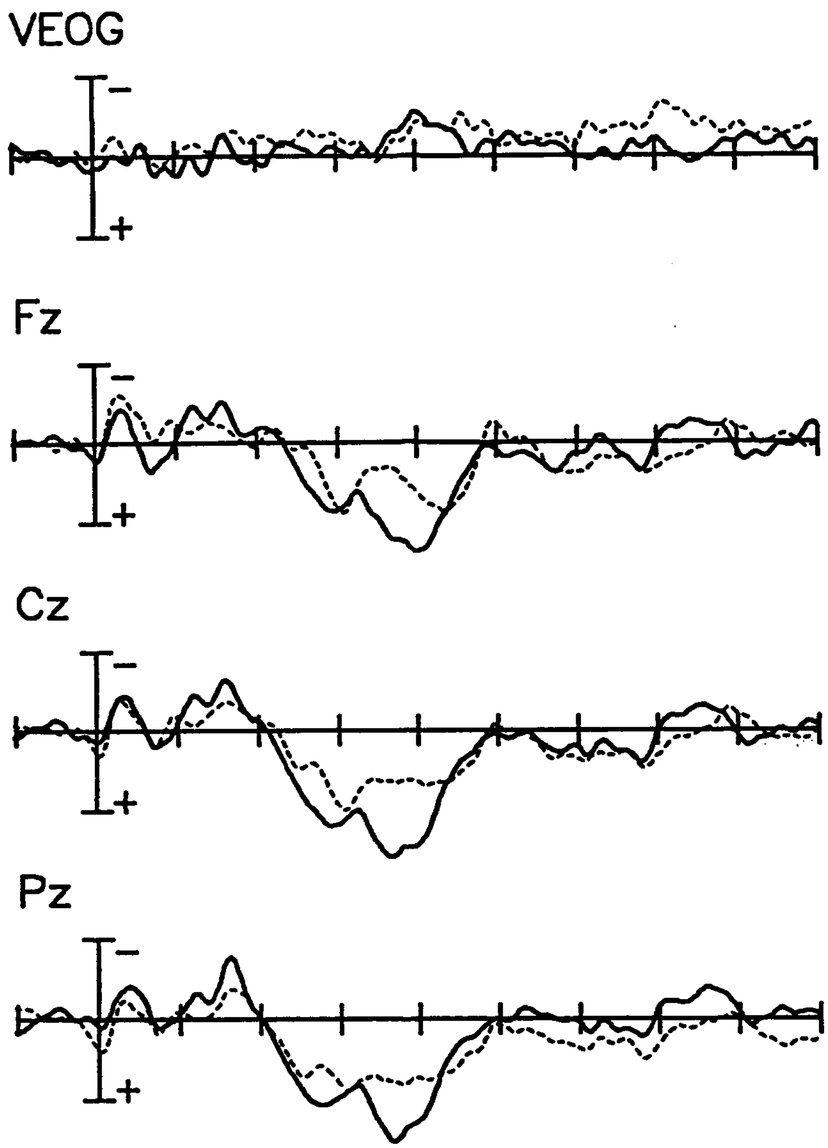

Figure 7 -- ERPs time-locked to visual probes; grand averages of seven repeated subjects. Solid lines are ERPs from the first six minutes of alert runs; dashed lines are ERPs from the first six minutes of drowsy runs.

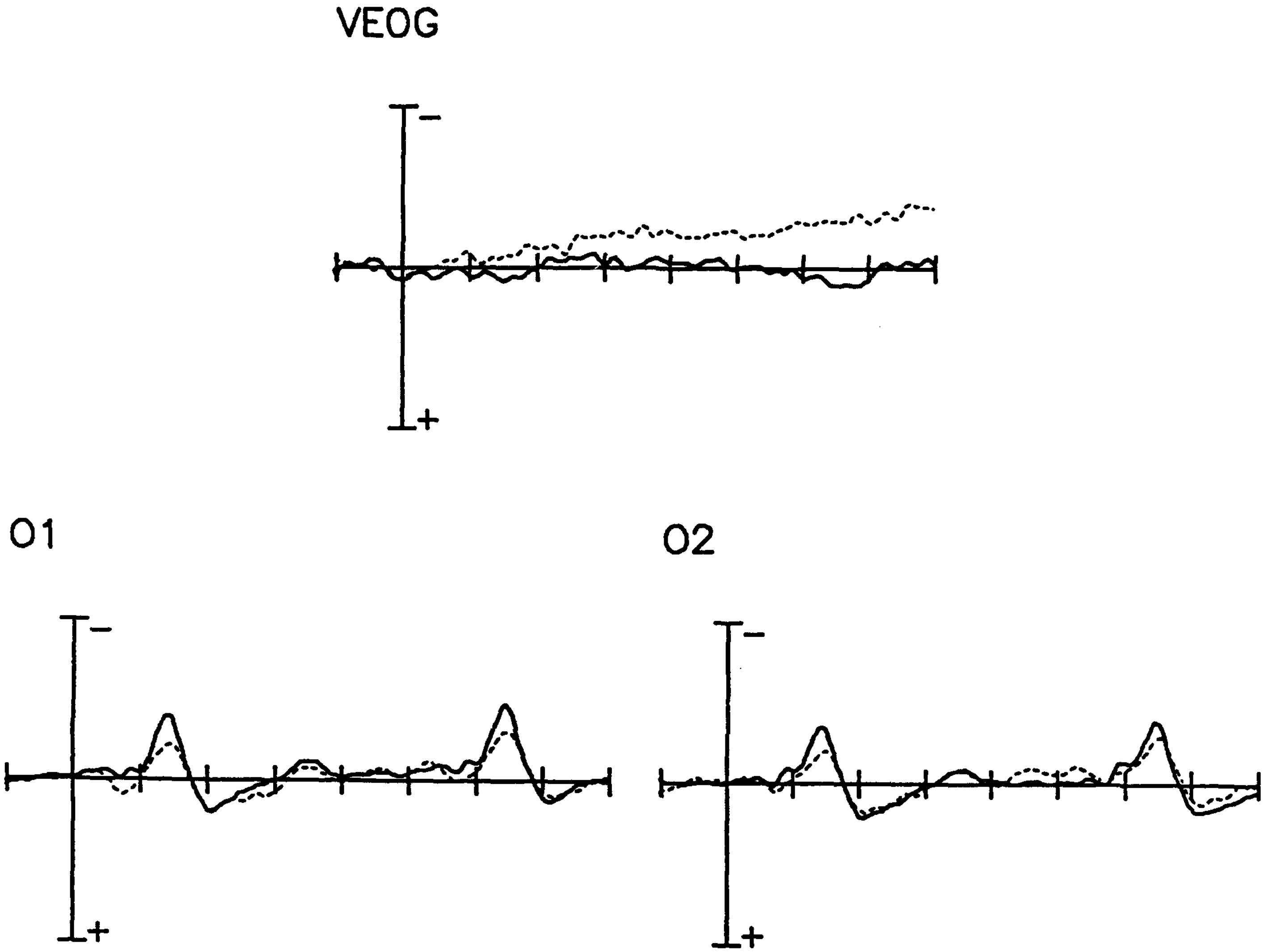

Figure 8 -- ERPs time-locked to screen updates; grand averages of seven repeated subjects. Solid lines are ERPs from the first six minutes of alert runs; dashed lines are ERPs from the first six minutes of drowsy runs.

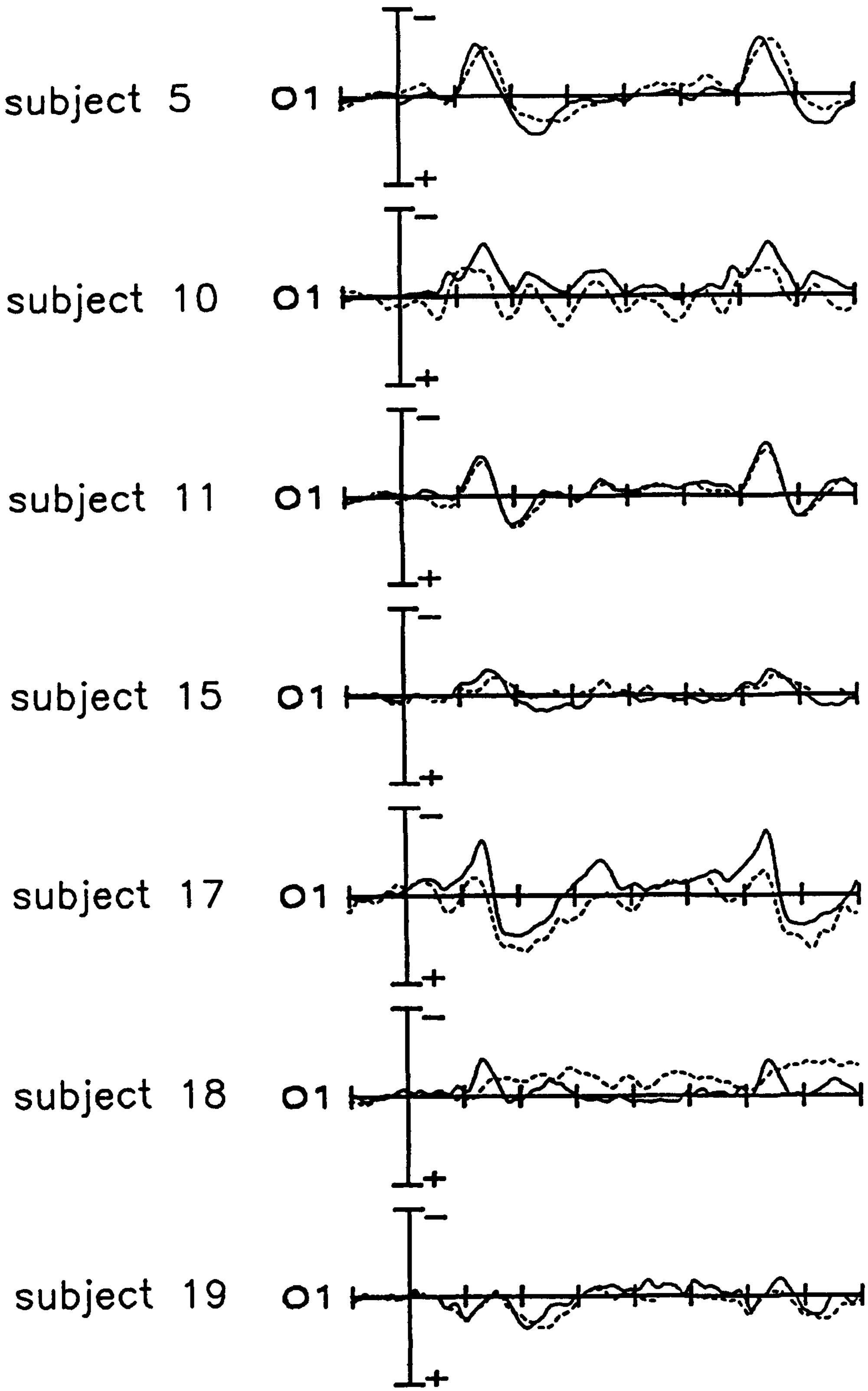

Figure 9 -- ERPs following screen updates, repeated subjects, in the first 6 minutes of alert (solid) and drowsy (dashed) runs.

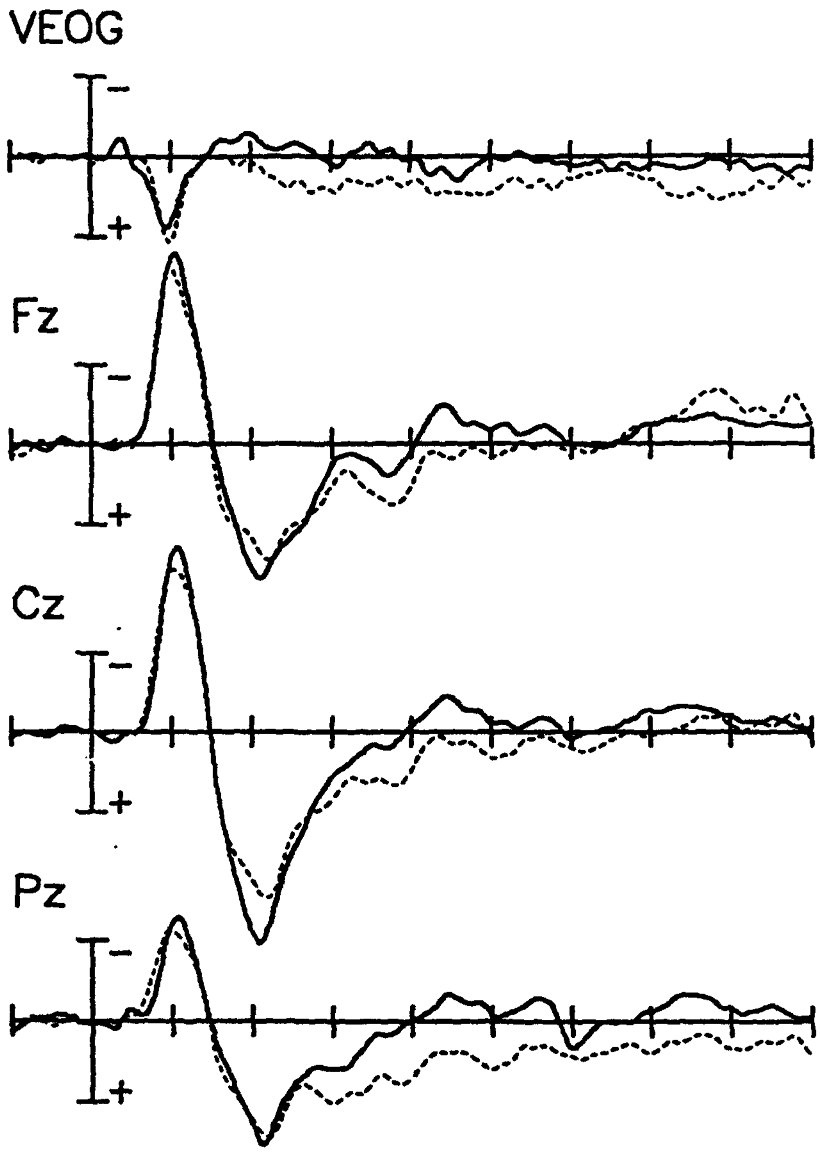

Figure 10 -- ERPs time-locked to auditory probes; grand averages of seven repeated subjects. Solid lines are ERPs from the first six minutes of alert runs; dashed lines are ERPs from the first six minutes of drowsy runs.

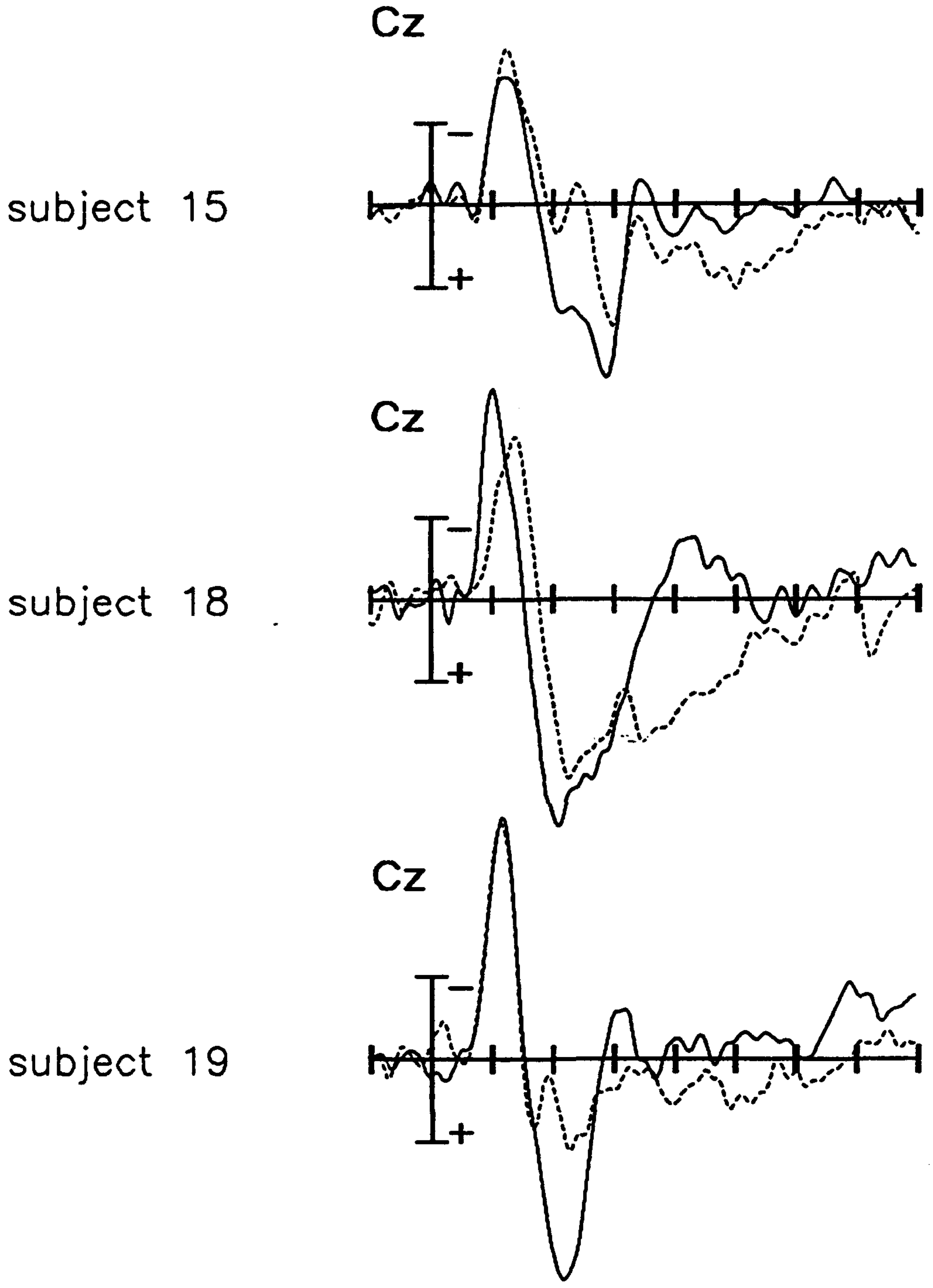

Figure 11 -- ERPs time-locked to auditory probes, at Cz for three subjects in the first six minutes of the two (60-minute) experimental runs. Solid lines indicate ERPs from alert runs; dashed lines indicate ERPs from drowsy runs.

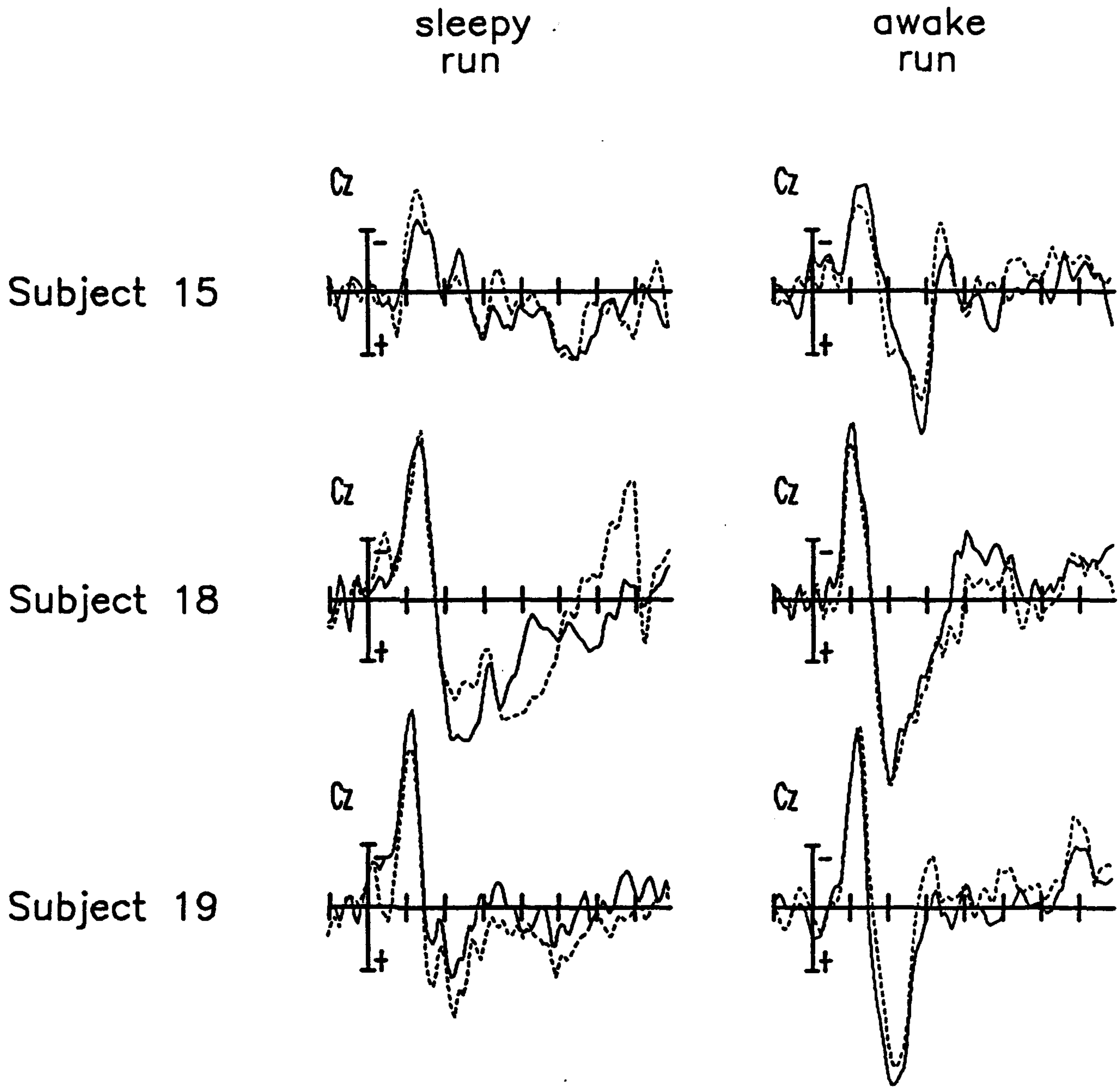

Figure 12 -- ERPs time-locked to the auditory probes occurring shortly before growing targets (solid lines) and shortly before flashing targets (dashed lines) at Cz for three subjects in the first six minutes of the two (60-minute) experimental runs.

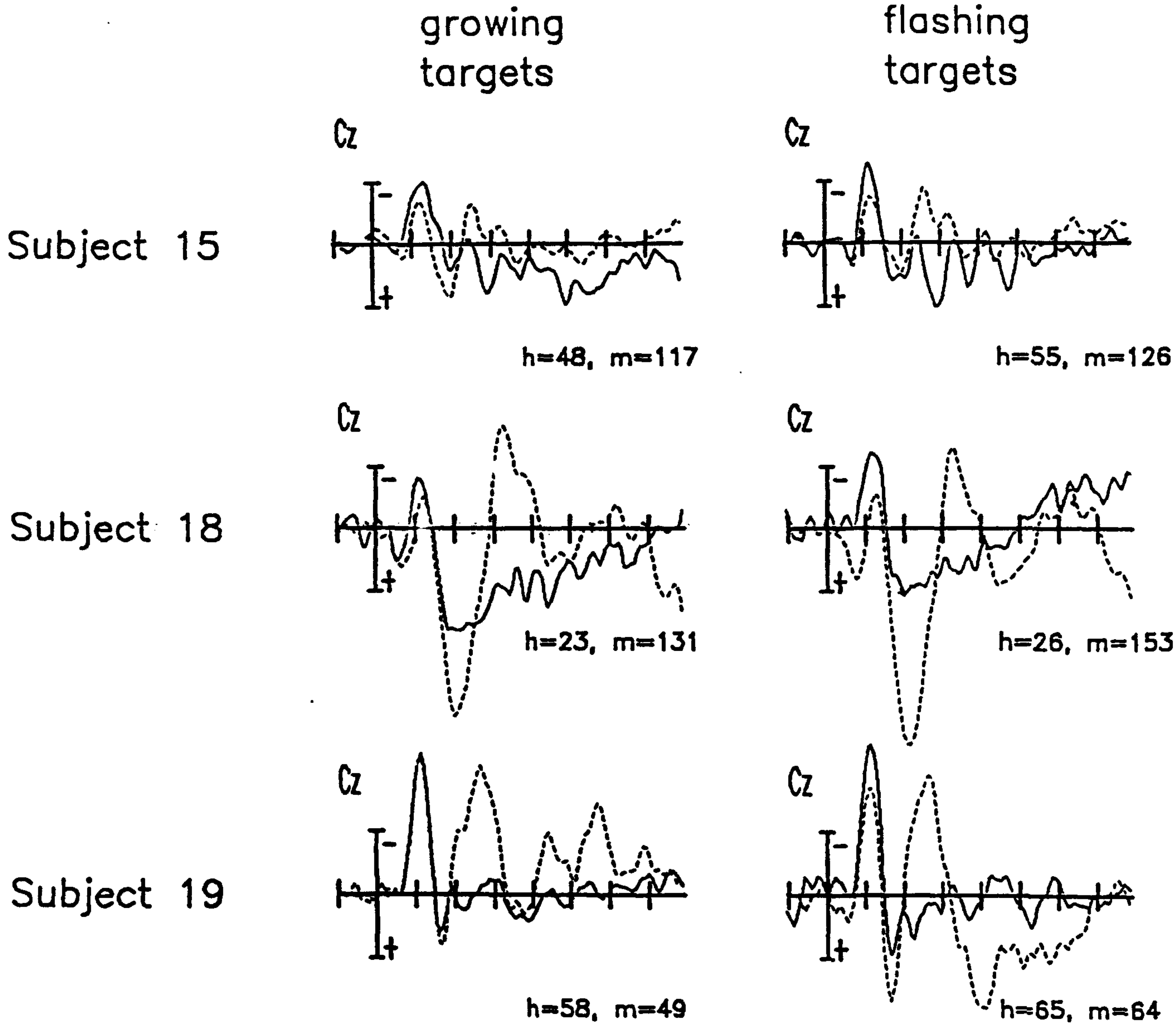

Figure 13 — ERPs time–locked to the auditory probes, pre–ceding targets, at Cz for subjects in the low–performance group. Solid lines are to probes before hits, dashed lines are to probes before misses. Numbers under the waveforms indicate the number of sums in the averages of probes before hits (h) & misses (m).

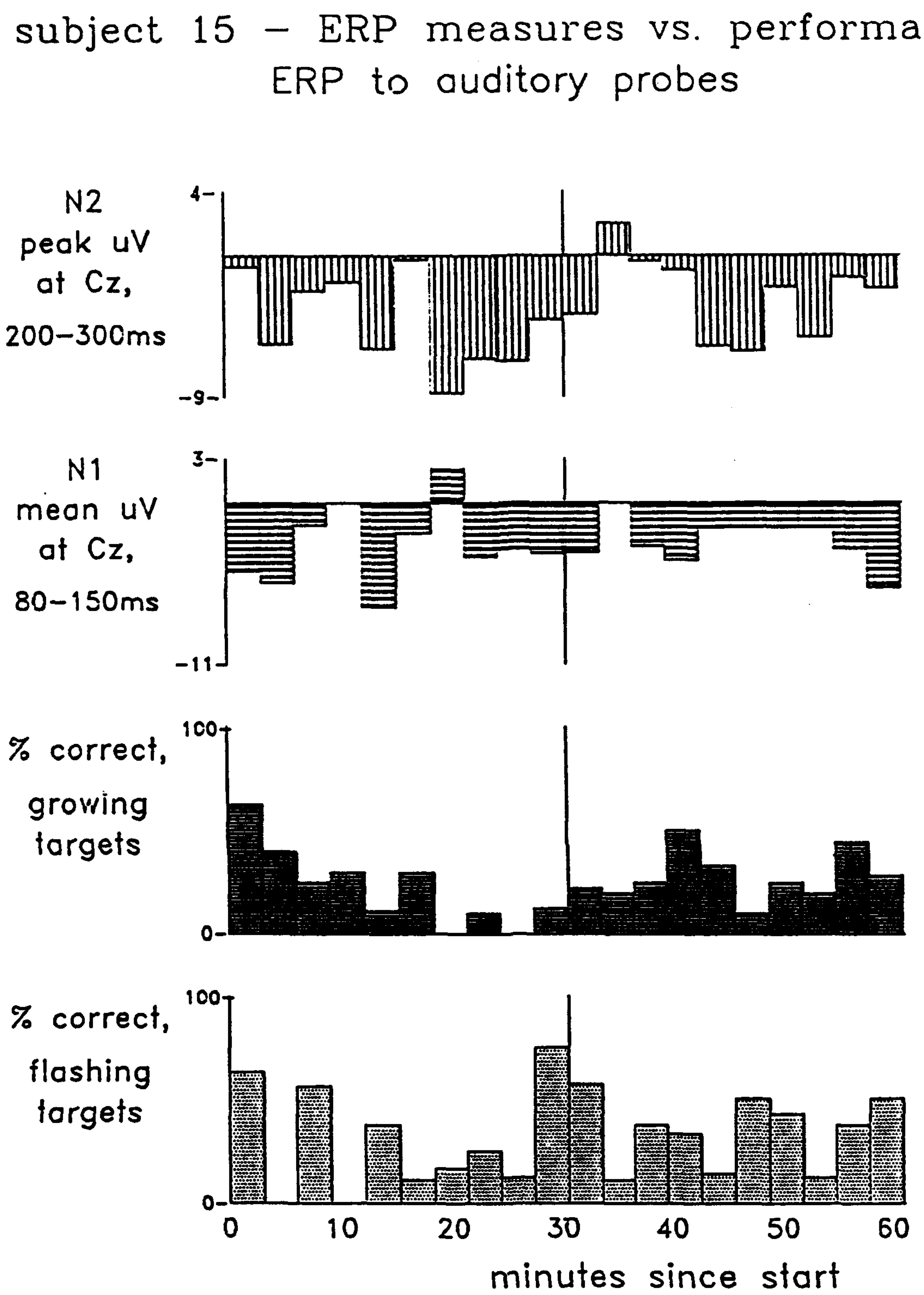

Figure 14 –– Changes in ERP amplitudes and target detection performance over one hour sessions for subject 15 (drowsy run). Successive bars give ERP amplitudes or percent correct detections averaged over successive three–minute intervals of the session.

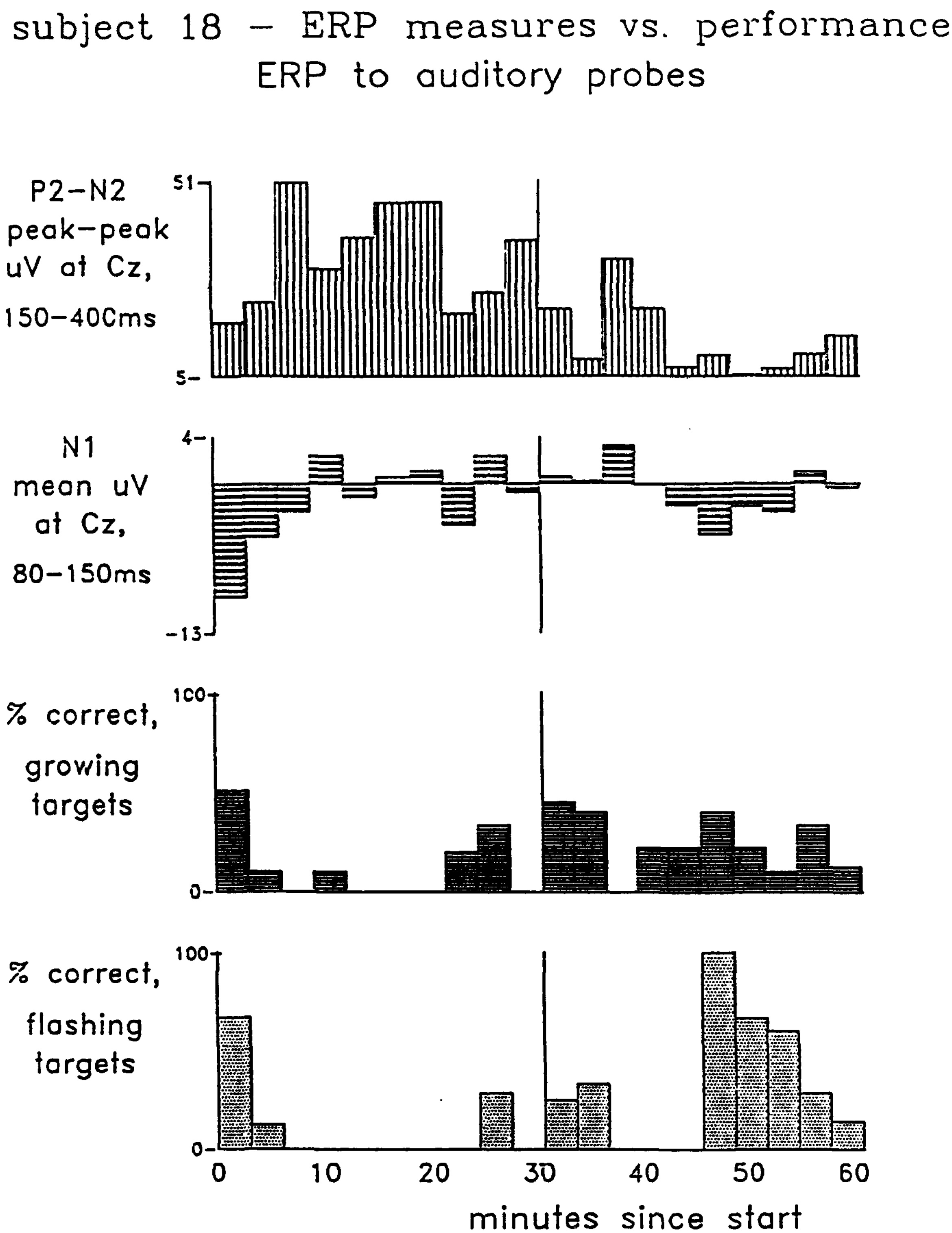

Figure 15 –– Changes in ERP amplitudes and target detection performance over one hour sessions for subject 18 (drowsy run). Successive bars give ERP amplitudes or percent correct detections averaged over successive three–minute intervals of the session.

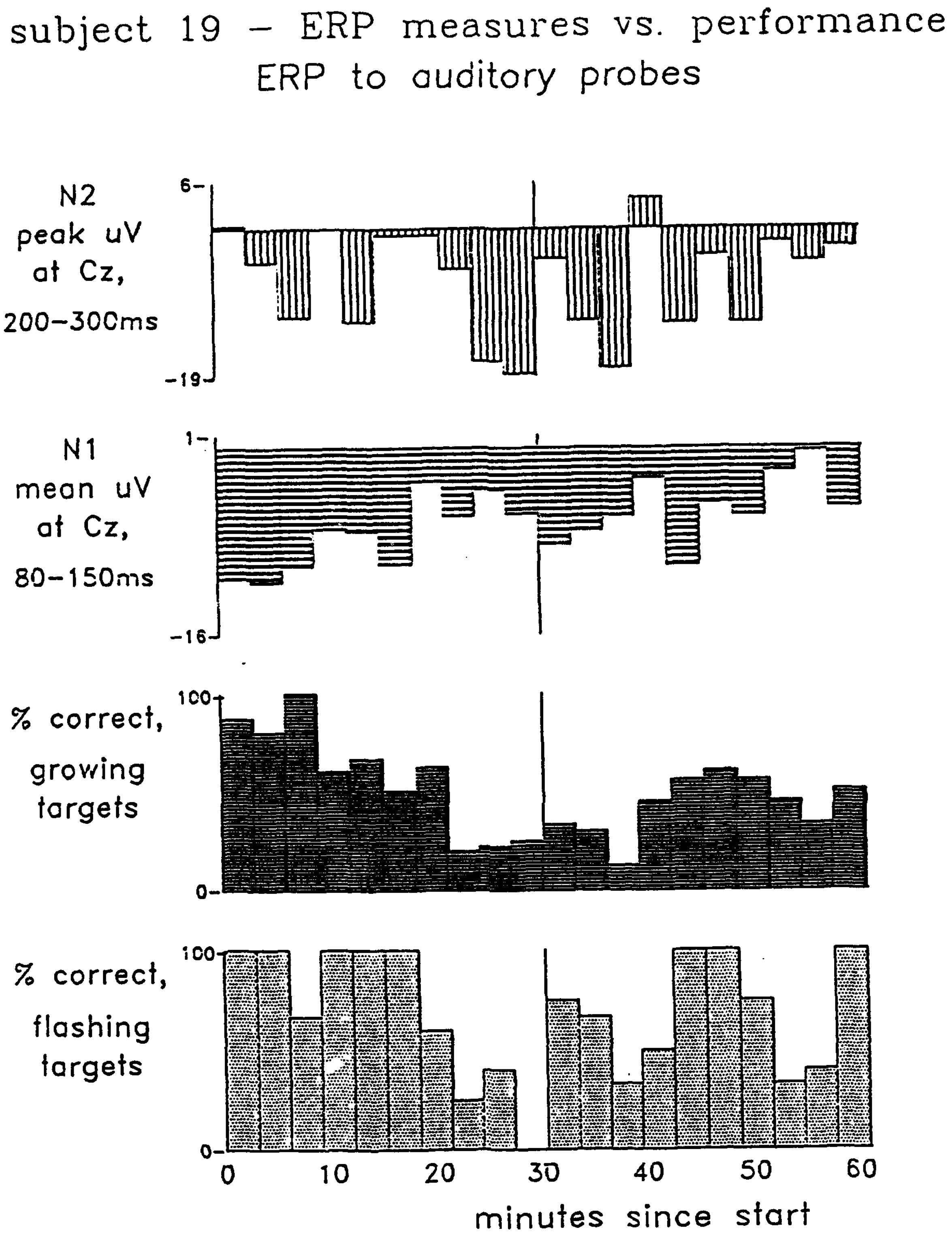

Figure 16 –– Changes in ERP amplitudes and target detection performance over one hour sessions for subject 19 (drowsy run). Successive bars give ERP amplitudes or percent correct detections averaged over successive three–minute intervals of the session.